

Original Article

Low Flow Venovenous ECMO: An Experimental Study

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ABSTRACT

Clinical use of extracorporeal membrane oxygenation (ECMO) and carbon dioxide removal (ECCO₂R) have become well established techniques for the treatment of severe respiratory failure; however they require full cardiopulmonary bypass, representing major procedures with high morbidity. We theorized the possibility of an efficient low flow venovenous extracorporeal membrane gas exchange method. Four mongrel 12 kg dogs were submitted to venovenous extracorporeal membrane gas exchange via a jugular dialysis catheter using a low flow (10 ml/min) roller pump and a membrane oxygenator for a period of four hours. Respiratory rate was set at 4 breaths/min with a FiO₂ of 21% and ventilatory dead space was increased. Adequate gas exchange was obtained (pO₂ 139, pCO₂ 24, Sat 99.4%), without major hemodynamic changes or hematuria. Our results demonstrate the feasibility of a low flow, less aggressive system. Further research should be considered.

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Figure 1
Blood gas analyzer with integrated roller pump.

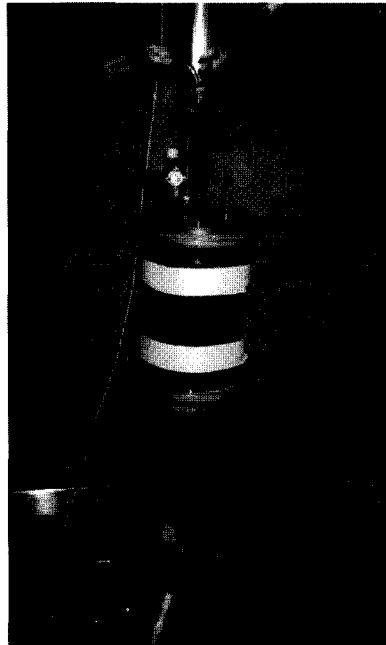


Figure 2
Membrane oxygenator.



Figure 3
Simple vascular access with a double lumen dialysis catheter.

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) and extracorporeal carbon dioxide removal (ECCO₂R) have been adopted as means of strong respiratory support. (1-3) Conventional extracorporeal support systems require high blood flow rates in the extracorporeal circuits to achieve optimal oxygenation or carbon dioxide (CO₂) elimination. (3,4) Common complications during long term extracorporeal life support with full flows are hemodynamic lability, anticoagulation related bleeding problems and infections. (5)

Actually, current extracorporeal life support systems require expensive cardiopulmonary bypass devices and of highly trained personnel which complicate the settings and elevate costs, limiting the availability of these procedures to few centers.

We considered the feasibility of performing efficient extracorporeal membrane gas exchange with low flows and a less invasive cost effective method.

MATERIALS AND METHODS

All animals used in this study received humane care in compliance with the "Institutional Animal Care and Use Committee Guidebook." (6)

Four male 12 kg mongrel dogs were submitted to venovenous extracorporeal membrane gas exchange via a percutaneous internal jugular double lumen dialysis catheter.

The animals were anesthetized with diazepam (300 mcg/kg), fentanyl (3 mcg/kg) and pancuronium (80 mcg/kg). Orotracheal intubation was performed and maintenance was achieved with fentanyl and pancuronium. All animals were mechanically ventilated at a respiratory rate of 12 breaths/min with FiO₂ 21%, catheters were placed and baseline hemodynamic parameters as well as arterial blood gases (ABG) were obtained.

The extracorporeal circuit comprised a low flow (10 ml/min) roller pump part of an "on line" arterial blood gas analyzer^a (Figure 1), and its set of 1/16" tubing, connected to a hollow fiber membrane oxygenator^b (Figure 2). Vascular access was obtained by percutaneous catheterization of the right internal jugular vein with an 8 Fr conventional double lumen dialysis catheter (Figure 3). The activated clotting time (ACT) was monitored with the Hemochron^c. Heparin was infused to maintain an ACT of 300-400 seconds. The circuit was primed with 250 ml of lactated ringer's solution, of which 220 ml was for the oxygenator.

The pressure gradient across the membrane was registered. Countercurrent dry oxygen was delivered at a flow of 800 ml/min. The experiment started by reducing the respiratory rate to 4 breaths/min and increasing the ventilatory dead space by the addition of 2 meters of tubing between the orotracheal tube and

- a Mallinckrodt Gem 6 Plus, Mallinckrodt Sensor Systems Inc., Ann Arbor, MI 48108
- b Polystan Safe-1, Polystan Inc., Copenhagen, Denmark
- c International Technidyne Edison, NJ 08820

Table 1
Hemodynamic parameters during the experiment (mean).

	Prepump	Pump
Heart Rate (bpm)	138	152
MAP (mmHg)	109	110
PAP (mmHg)	13	12
CVP (cm H ₂ O)	10	10
Urine Output (ml/Hr)	49	49

MAP = mean systemic arterial blood pressure
PAP = mean Pulmonary arterial blood pressure
CVP = central venous pressure

Table 2
Performance of the low flow extracorporeal system (mean).

	Basal	Hypoventilation	Pump
pO ₂ (torr)	113	75	139
pCO ₂ (torr)	32	42	24
SATURATION %	97.5	93	99.4
pH	7.42	7.30	7.36
hematocrit %	34	34	32
pre oxygenator pressure (mmHg)			80
post oxygenator pressure (mmHg)			80

Table 3
Blood gas values at inlet and outlet of oxygenator.

	Oxygenator Inlet	Oxygenator Outlet
pO ₂ (torr)	18	167
pCO ₂ (torr)	117	5
SATURATION %	33.5	99.8

the ventilator. Body temperature was maintained at 34-35°C. After 15 minutes of induced hypoventilation, pumping was started and maintained for 4 hours. Two control ABGs were taken during hypoventilation and then every 15 minutes using the blood gas analyzer part of the extracorporeal circuit*. Complete hemodynamic monitoring was performed during the whole experiment.

RESULTS

HEMODYNAMIC BEHAVIOR

During the extracorporeal circulation period, heart rate increased by 10% (138 to 152 bpm). Mean systemic arterial pressure (MAP), central venous pressure (CVP) and mean pulmonary arterial pressure (PAP) remained unchanged. Urine

output averaged 49 ml/hour, with no output changes before or during the pumping period (Table 1). No hematuria was observed during the procedure.

EXTRACORPOREAL GAS EXCHANGE EVALUATION

Induced hypoventilation (4 breaths/min) plus augmentation of the ventilatory dead space modified the initial arterial blood gas values by a 33.6% and a 4.3% reduction in arterial pO₂ and saturation respectively and pCO₂ increased by 31.2% (pO₂ 75, SAT 93%, pCO₂ 42).

Arterial blood pH was reduced during hypoventilation from 7.42 to 7.30, and was treated with minimal doses of sodium bicarbonate (Tables 2 and 3).

During the pumping stage adequate extracorporeal gas exchange was obtained as evidenced by an elevation in pO₂ and saturation with a reduction in carbon dioxide value (pO₂ 139, Sat 99.4%, pCO₂ 24.0). pH levels ranged from 7.27 to 7.52 with a mean of 7.36 and there were no major changes in hematocrit values during the study. There was no transmembrane gradient.

DISCUSSION

Extracorporeal circulation for respiratory failure evolved in the 1970s from a general dissatisfaction with the conventional methods of therapy. (7)

In the 1990s, extracorporeal life support systems (ECMO - ECCO₂R) have proven adequate clinical results in both pediatric and adult patients with severe respiratory insufficiency non-responsive to maximal ventilatory therapy (8-10); however, they represent major procedures comprising high flow cardiopulmonary bypass. High extracorporeal flow rates require large vascular access, most of which need to be surgically inserted; increasing the morbidity of the procedure.

Recent advances (11-13) in the design and development of new pumps, circuits and membranes have resulted in better and high performance extracorporeal life support techniques. It is our belief that any reduction in the invasiveness of these procedures, and of associated complications will play a major role in defining its applications.

Our hypothesis was that a less invasive, less aggressive and simple method for veno-venous extracorporeal membrane gas exchange, could be effective as an adjunct therapy to conventional mechanical ventilatory support.

The results of this study demonstrate the capabilities of low flow extracorporeal circulation for membrane oxygenation and carbon dioxide removal; as reported by Young and associates (12).

We decided upon a veno-venous system because it involves a less aggressive approach and it offers a simple cannulation option.

Other groups (12-13) have demonstrated the use of the animal's own blood pressure to generate flow across the membrane, using an arterio-venous system. However, we consider

that if the main target of the extracorporeal support is carbon dioxide removal, this is better accomplished by raising the CO₂ content of the blood entering the membrane, like in veno-venous bypass.

Regarding the equipment used during the study, the circuit formed by the ABG analyzer and its integrated pump is simple and easy to operate, with the advantage of being portable and it can be utilized in areas of reduced space. Another advantage is that the "On Line" analyzer also makes determinations of electrolytes, hematocrit and venous blood gases.

We agree that even though we were able to oxygenate and remove carbon dioxide during the experiment, we did not quantify the efficiency of the procedure. Further research will be done with higher flows, minimal anticoagulation, heparin coated tubing, smaller circuits and different oxygenators, in order to standardize the optimum setting and determine, if possible, an oxygenation and CO₂ removal coefficient.

In summary, we conclude that efficient extracorporeal membrane gas exchange can be performed with conventional hemofiltration vascular access and low flow pumps.

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